AN AUTOMATED ALARM PROGRAM FOR HP5071A FREQUENCY STANDARDS

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Abstract

In the 1997 PTTI paper titled "Maintenance of HP5071A Primary Frequency Standards at USNO," Chadsey and Kubik presented findings to that date on USNO's efforts to evaluate the devices' performance according to their internal operational parameters. This paper presents methods used to evaluate those parameters and automatically detect abnormal operation. Some of the developmental difficulties will be discussed, as will some general guidelines on the tolerances USNO uses to detect problems with the HP 5071A frequency standards.

INTRODUCTION

The importance of monitoring of the operating parameters of the HP 5071A cesium frequency standard was covered in a 1997 PTTI paper by Chadsey and Kubik [1]. It was noted that by having a computer periodically inquire and permanently file the 22 parameters via the RS-232 connection, one could diagnose and in some cases predict the device's failure. All the data analysis was performed manually when that first paper was written. Manual analysis may be acceptable for some locations which have only a few HP 5071A devices, but when five or more devices are involved, the personnel costs go up very quickly. The need to regularly look at the parameters for over 40 devices at USNO in Washington, DC drove the development of automating the data analysis toward an alarm system. Warnings were to be issued whenever a device exhibited abnormal behavior.

THE PARAMETERS

A computer can be programmed to periodically poll an HP 5071A via the RS-232 connection. The parameters reported are: frequency offset, oscillator control percentage, rf 1 amplitude percentage, rf 2 amplitude percentage, Zeeman frequency, C field current, electron multiplier voltage, signal gain percentage, tube oven voltage, tube oven temperature error, oscillator oven voltage, ion pump current, hot wire ionizer voltage, mass spectrometer voltage, SAW tuning voltage, DRO tuning voltage, 87 MHz PLL voltage, uP clock PLL voltage, +12 volt supply voltage, -12 volt supply voltage, 5 volt supply voltage, and internal temperature. A detailed description of these is found in the operators manual and the 1997 paper [1]. These parameters tell a person how the hardware of a device is operating. A hardware failure may or may not be noticeable in a

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device's performance. If the failure affects performance, the question becomes: how long before it is noticeable? A power supply failure usually will show up immediately in the performance, while a cesium beam tube end of life may not show up for several weeks, depending on the accuracy of the measurement system.

THE BASIC PROGRAM

The original program used at USNO to monitor the HP 5071A parameters was quite basic. Its first duty was to take the parameters as they were filed and put them in a more readable form. Several different formats were required depending on whether a person was to look at the data or the newly formatted data were to be used as an input into a plotter or spreadsheet program.

From this first reformatting program, the next logical step is to have the program check each parameter for reasonableness. If a measurement exceeds a certain limit, a warning message is printed. If, as in this case, there are several parameters which have to be checked, one has to write a series of such tests. Such a test usually has both upper and lower limits. For example, a power supply can fail and stop working if a capacitor blows open. On the other hand, if the capacitor blows to a short, the voltage could go very high, causing damage in other components. Thus, the programmer needs to write the source code with the ability to check 22 different ranges of values for the HP5071.

However, the parameter range for any two devices may be and usually is different. The difficulty is that the difference between the ranges of the two devices is larger than the tolerance for catching the device failures. For example, one device may be performing very well with the typical ion pump current of 0.5 or less microamps, as shown in Figure 1.

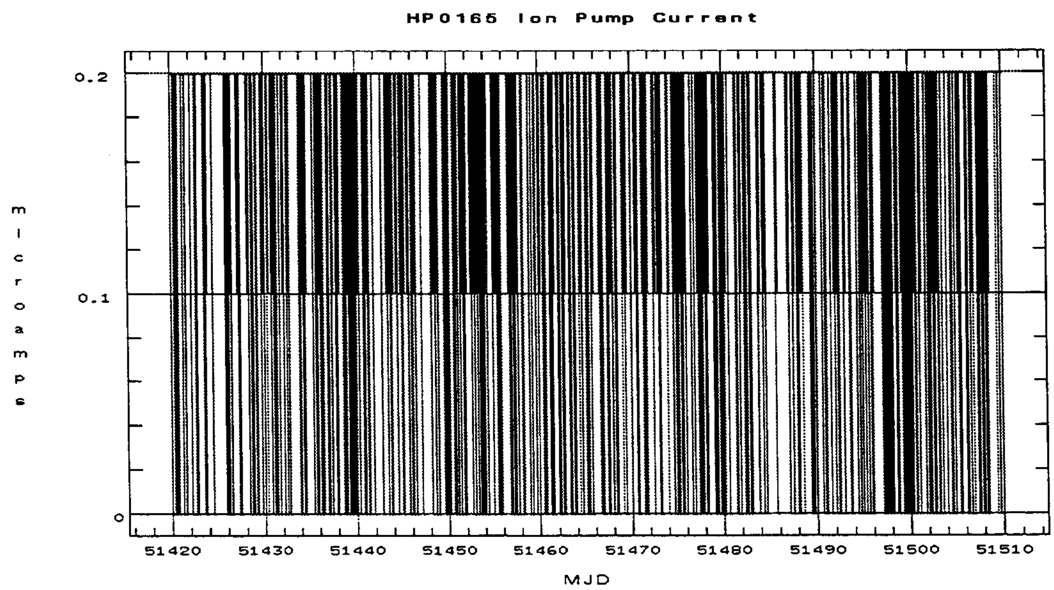

Figure 1. Typical Ion Pump current for an HP5071 Cesium-Beam Frequency Standard

Another device, however, can be performing equally well while running an ion pump current over 1.0 microamp, as shown in Figure 2.

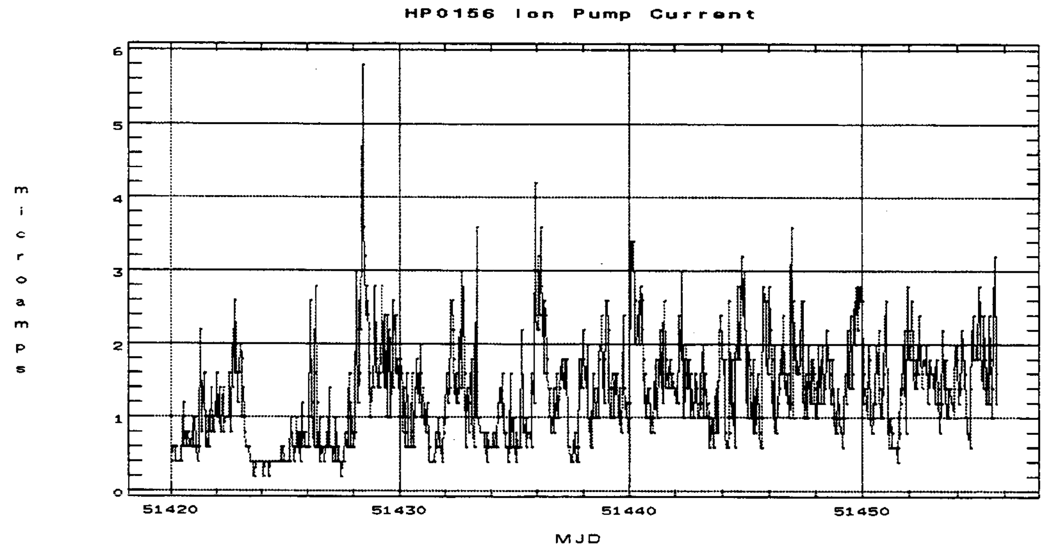

Figure 2. A typical Ion Pump current for an HP5071 Cesium-Beam Frequency Standard. Although the current is above the typical value and is not well regulated, the device is performing as well as the one shown above. This device must be closely watched for performance changes.

The two devices show no difference in their frequency stability, as demonstrated by their sigma-tau plots shown in Figure 3. To allow for this diversity, the programmer must either write a separate program to check the parameters of each device or create a configuration file to let the program know the tolerances for each device. The configuration file idea is really not difficult if one uses matrixes to store the limits for each device's parameters.

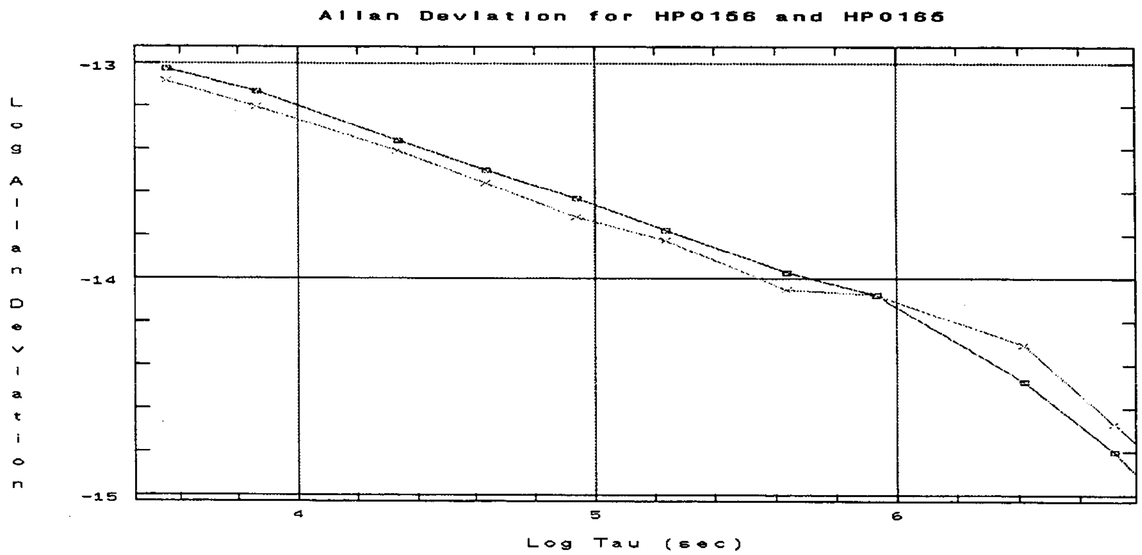

Figure 3. Allan Deviation Plot comparing the performance of two devices with vastly different Ion Pump characteristics. HP0156 is shown using squares while HP0165 is shown using Xs.

CHANGES IN PARAMETERS

Up until now, all parameters have been discussed as though they only range within fixed limits and have no trends that would change the limits. For example, a +12 volt power supply would always be between +12.0 and +12.5 volts. Any deviation from that range would indicate a performance affecting failure of some type. While this is true for power supplies and most of the other parameters, it is not true for all of them. The best example is the electron multiplier voltage.

The electron multiplier (EM) voltage changes as the cesium clock ages. When the tube is new, the EM voltage will start out at some value, say 1600 volts. Over the first 6 months to a year that voltage will slowly decrease as much as 200 to 300 volts. After bottoming out, the EM voltage will slowly increase as the tube ages. Because the value changes slowly over time, fixed limits that are too narrow will eventually be exceeded and an error reported when in fact one did not occur. If the limits are set too wide, a real error will go undetected. The program must be able to learn what is normal before determining when the parameter has gone beyond normal operating tolerances (see Figure 4).

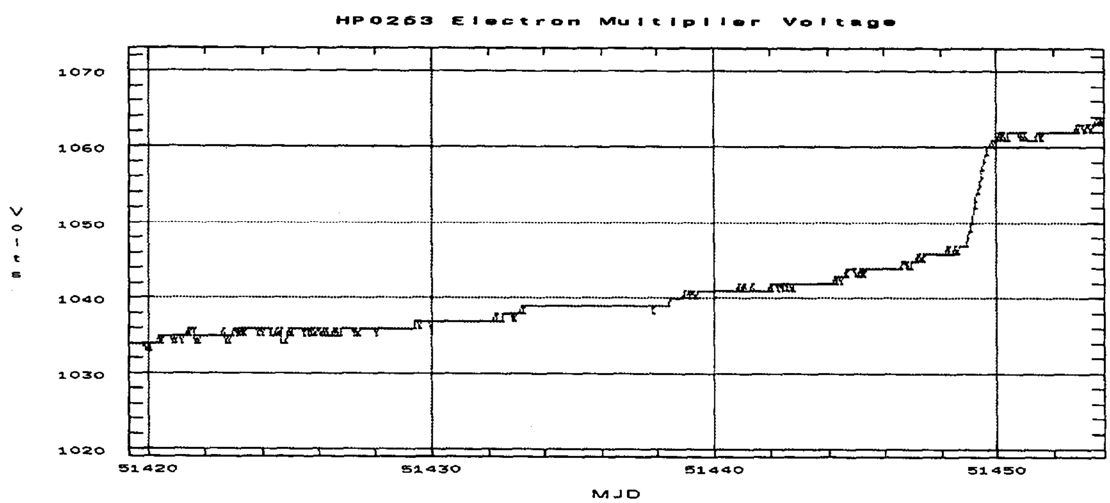

Figure 4. A typical Cesium-Beam Frequency Standard has a slowly varying Electron Multiplier voltage which the alarm program must track to detect a sudden change. The >9.0 volt change occurring beginning on MJD 51449 is the indicator that the cesium supply has been depleted in this tube. Performance will start to degrade sometime in the next few days to weeks.

The challenge of writing a self-learning program involves understanding and implementing one's mental analytical techniques. This is almost always easier said than done. One must consider how long a period of time must be used to determine normalcy. If the period is too short, the noisiness of the data may hide the abnormal events the alarm program is supposed to be detecting. If the period of time is too long, long-term data trends may induce the appearance of noise or may cause the program to ignore a subtle yet significant change affecting performance. While determining the proper period for data analysis, one must estimate the expected range of variation for normal data.

Many hours of manual data analysis and experimentation were necessary to find criteria that could be applied to all the parameters. (A programmer usually wants to make the source code as short and universal as possible.) The present alarm program uses the data collected over a 5-day period and linear-fitted to determine normality. It was found that data analysis periods of more than 7 days required the tolerance limits on some parameters to be too large to catch abnormal behavior in the devices. Shorter analysis periods tended not to average out the measurement noise sufficiently for some parameters. The program compares a theoretically normal point to the actual measured value. An alarm occurs if they differ by some *a priori* amount which must be empirically determined. How far into the future the linear-fit solution point must be is controlled by the rate at which a parameter can change during normal operation. Again, if one does not look the proper distance into the future, a false alarm can occur. The present program predicts 48 hours in advance. While 24 hours was sufficient for most parameters, it would not work for three very important parameters (i.e., RF amp #1, RF amp #2, and electron multiplier voltage). The prediction time was made the same for all parameters to make the program as simple yet universal as possible.

PARAMETER TESTING

Next, we consider what the program should deem abnormal and cause an alarm message to be generated. At least two levels of alarm conditions were found to be necessary. The lower level is a warning that something might be failing, or had just failed, but had not yet affected the device performance. The higher level alarm warns of performance affecting failure. For example, a +12 volt power supply changing 0.1 or 0.2 volts may not affect performance or clock operations, but could indicate that something could be starting to fail. On the other hand, a drop in the power supply voltage from +12 volts to +0.2 volt, as shown in Figure 5, would affect the device's performance and operation, requiring the device's immediate repair.

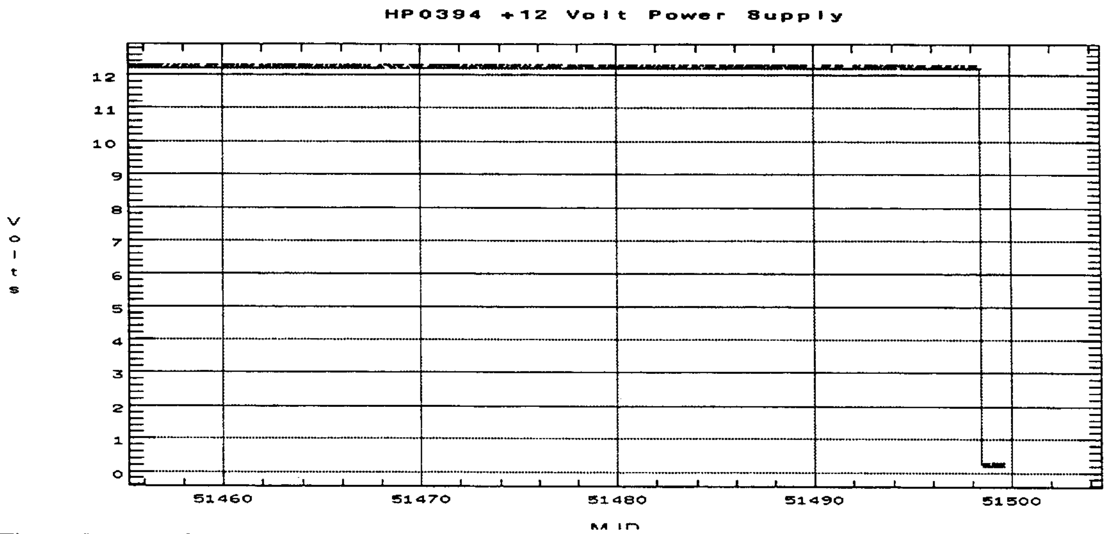

Figure 5. A performance affecting drop in the +12 volt power supply in an HP 5071 Cesium-Beam Frequency Standard.

As stated earlier, each device has a "personality" of its own. No two devices have exactly the same operating characteristics for all the parameters. However, some of the parameters (i.e., Zeeman frequency and signal gain) have the same expected values and tolerances in all the devices. To make the program as universal as possible, it was decided to treat all parameters the same and have low-and high-level alarm limits for all of them. This gives the added benefit of making each device's characteristics file somewhat self-documenting. A parameter (e.g., ion pump current) may be different for a particular device and the device still be operating and performing perfectly well for a site's timing operations. The following table gives the characteristics of a typical HP5071.

HP0101-5071		HP0101	78_125			
cesium/C101		51513.399				
0.0000	0.000	0.000	0.000	f/s	Freq_offset	F_off
0.2779	0.100	-20.000	45.000	pc	Osc_control	O_ctl
31.0212	0.100	15.000	35.000	pc	RF_amp_1	RF_1
29.6668	0.100	15.000	35.000	pc	RF_amp_2	RF_2
39949.0000	0.000	39949.000	39949.000	Hz	Zeeman_freq	Z_frq
12.1133	0.001	12.100	12.200	mA	C-field	C_fld
1357.5823	9.000	0.000	2552.000	V	E_multiplier	E_mlt
14.4000	0.000	14.400	14.400	pc	Signal_gain	S_gn
7.5279	0.100	7.000	9.000	V	CBT_oven	C_ovn
0.0032	0.200	-0.200	0.200	C	CBT_error	C_err
-8.7000	0.100	-9.000	-8.500	V	Osc_oven	O_ovn
0.2040	0.200	0.000	0.500	uA	Ion_pump	I_pmp
1.0042	0.100	0.900	1.100	V	HW_ionizer	HW
11.7000	0.100	10.000	14.000	V	Mass_spec	Mass
-0.9000	0.100	-2.500	2.500	V	SAW_tuning	SAW
5.5000	0.050	5.000	7.000	V	DRO_tuning	DRO
1.2964	0.100	1.000	3.500	V	87MHz_PLL	87PLL
3.2000	0.050	2.500	3.500	V	Up_clock_PLL	UpPLL
12.3000	0.100	12.000	12.500	V	+12V_supply	P12V
-12.1042	0.100	-13.000	-12.000	V	-12V_supply	M12V
5.2052	0.100	5.000	6.000	V	+5V_supply	P5V
43.1294	0.400	30.000	50.000	C	Thermometer	Temp

Table 1. The first line contains the device's complete name (i.e., the chasis number and model number of the device), an abbreviation of the device name, and the device's location (i.e., USNO Washington building 78 in room 125). The second line contains the data file name and the MJD with fractional date of when the projected points were last calculated. The rest of the file contains the specifics about each parameter. (Note: USNO does not put frequency adjustments into its clocks. Device rates and drifts are accounted for through computations and not by hardware adjustments. Thus, frequency offset is set to zero in all USNO clocks.)

Each parameter characteristic line is calculated independently and then assembled into the characteristics file format. The first field of numbers is the parameters' current expected values (the 2-day prediction from the 5-day linear fit to the data). The second field is the low level alarm level. When a measured value exceeds the limits of the low-

level alarm tolerance added to the predicted value, a warning is issued. When the low-level alarm value is zero, an alarm occurs for any deviation from the first field value. The third and fourth fields are the minimum and maximum tolerable levels for the parameter respectively. If the parameter value should go outside these values, the device probably is experiencing a failure that could affect its performance. The fifth field is the units of measure. The sixth field is the parameter name and the seventh field is the name abbreviation. The parameter name and name abbreviation are used in different alarm messages.

RESULTS

Over the past two years, this program has given some minor false alarms. Those alarms were caused by the device's incorrect output values; these are usually one-point anomalies. The linear processing done to learn the normal operational value of each parameter does not reject these anomalies, but warning messages about them are issued. The operator must double-check that there is no real problem. One must remember that this is an alarm program. Outlying points should not be filtered out, as they would in most data processing. This should be noted by users of any automated alarm system. The checks are only as valid as the data quality is good. Data verification is still required.

CONCLUSIONS

A program has been written at USNO to automatically check the operational parameters available from an HP 5071 model cesium-beam frequency standard. The program warns operators if a parameter does not meet marginal or critical tolerances which might or will affect the device's performance. It is sophisticated enough to learn of slowly changing parameter values in order to better detect and report abnormal values.

REFERENCES

[1] H. Chadsey and A. Kubik, "Maintenance of HP5071A Primary Frequency Standards at USNO," in Proceedings of the 29th Annual Precise Time and Time Interval (PTTI) Systems and Applications Meeting, 2-4 December 1997, Long Beach, California, pp. 49-59.